Using a Photogate in an APS Detector*

H.S. Matis,[1] F. Bieser,[1] Y. Chen,[2] R. Gareus,[1] S. Kleinfelder,[2] M. Oldenburg,[1] F. Retiere,[1] H.-G. Ritter,[1] H.H. Wieman,[1] S.E. Wurzel,[1] E. Yamamoto[1]

[1] *Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720*

[2] *Department of Electrical Engineering and Computer Science, University of California, Irvine, CA 92697*

Parameters of an Active Pixel Sensor (APS) [1], such as signal to noise and readout speed, are important when designing a vertex detector. High signal to noise is needed to suppress fluctuations. Correlated double sampling (CDS) is a traditional method of reducing noise, particularly kT/C reset noise. It requires two full reads, full frame storage, and an external subtraction. The two reads slow down the readout process, so finding a method of reducing noise without this penalty is important.

A photodiode node must have a sufficiently small capacitance to give a high charge to voltage conversion. This high gain requires that the area of the photodiode be kept small, yet this very "necessity" causes the diode to pick up an even smaller fraction of the total liberated charge in the field-free epi region. The remaining charge will diffuse out to neighboring pixels or will recombine. Thus even a best-compromise design results in a low signal to noise ratio. If charge could be collected on one pixel, an analog comparator could be used to determine when there was a hit.

One way of collecting the charge in a few pixels is a photogate. This structure has been used in CCDs and light sensitive APS devices [2]. The key advantage is that the collection region of a photogate may be large, yet the collected charge is transferred to a low capacitance readout node, preserving a high charge to voltage conversion ratio. Photogates can also make CDS more convenient, since they eliminate the requirement for complete frame storage of the first sample.

A photogate collects charge in a similar manner to a photodiode. Electrons created in the epitaxial layer diffuse until they migrate to a broad field region created directly below the large area photogate, which is biased at a higher potential. They are collected and held until the photogate voltage is dropped to below the transfer gate voltage. At this point, they migrate to the higher-potential, low capacitance, readout node. The readout node must be periodically reset and the photogate must be continually cycled to keep the region directly under the photogate depleted. In principle, the photogate can deliver both higher local charge collection by virtue of its large area and high charge-to-voltage conversion gain due to the charge transfer to a low-capacitance readout node.

To study whether a photogate can be used, we fabricated our third sensor – APS-3 with 20 µm pixels. The sensor was created in the 0.25 µm TMSC process of MOSIS.

First, we measure the charge spread for an incident particle. We sum the charge from an ^{55}Fe source around the highest pixel. We find the four-pixel sum by selecting the highest value of three adjacent pixels to the central pixel. The three-pixel sum removes the lowest outside pixel and the two-pixel sum uses the central pixel and the highest neighbor.

Fig. 1 shows these sums. The four-pixel sum is essentially identical to the three-pixel sum, so most of the charge is distributed among three pixels. Charge is collected over a much smaller range compared to a photodiode where a sum over 25 pixels is needed to collect the charge.

Unfortunately, there are many clusters, which do not have the full energy collected, because most of the events are not bunched around the full peak energy of approximately 250 ADC counts. Therefore, the photogate circuit often does not collects the full charge. Subsequent measurements with light have shown that it takes of order 10 ms to collect the full signal. As the time for the CDS read was 6.6 ms and the x-rays were distributed randomly throughout, there was not enough time to collect all of the charge from each interaction. We are examining this mechanism, to see whether we can find a way to reduce the collection time.

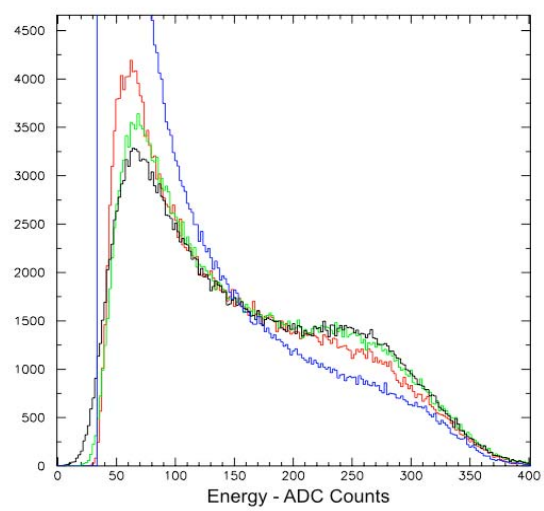

FIG. 1: Distribution of charge collected for the photogate. The top curve (blue) (near 250 counts) is for summing four adjacent pixels. The curves in descending order are sums of 3 (green), 2 (red) and 1 (blue) pixels.

REFERENCES

*Adapted from a contribution to the conference "Vertex 2003"

[1] H.S. Matis *et al,* IEEE Trans. Nucl. Sci. **50**, 1020 (2003).

[2] E.R. Fossum, IEEE Trans. On Electron Devices 44 (1997) 168.